CHAPTER VII

INDUSTRIAL UTILIZATION OF GEOPRESSURED GEOTHERMAL ENERGY

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A. INTRODUCTION

Discussion of the industrial utilization of geopressured geothermal energy is currently limited by the limited knowledge of the resource's distribution. However, the resource assessment activity in the Bureau of Economic Geology, The University of Texas at Austin, has identified a number of fairway or potential resource zones. These zones are located in Kenedy County; in and about Corpus Christi and Nueces Bays in Nueces, San Patricio, and Aransas Counties; in the coastal zones of Matagorda County; and in a crescent-shaped zone parallel to the coastline in Brazoria and Galveston Counties.

The Kenedy and Matagorda County zones are situated in rural areas with little or no industrial activity. The Corpus Christi and Brazoria-Galveston zones are in and adjacent to highly industrialized and urbanized districts. The rural zones will require the establishment of new industries for geothermal fluid utilization while the industrial-urban zones will require either new industry, expansion to existing industry, or modification to existing plant and process.

Proposed industries for geothermal fluid utilization can be considered with respect to fitting the industry to the available fluids; this has been the usual approach. An alternate approach is to fit the available fluids to the proposed industry. In order to follow the alternate approach requires consideration of ways to upgrade the quality of existing geothermal fluids or geothermal-derived or -energized fluids. The next section discusses these alternate approaches, especially the upgrade or beneficiation alternative.

DISCLAIMER

B. SURVEY VERSUS BENEFICIATION

The two philosophical approaches to geothermal fluid utilization mentioned above will be named survey and beneficiation in this report. Survey implies the search for suitable industrial uses of natural geothermal fluids. Beneficiation, named in analogy to mining industry processes which have as object the concentration and quality upgrading of ores and their derivatives, denotes the search for ways to upgrade natural geothermal fluids or their derivatives. In fact, beneficiation is the only way currently in use for commercial generation of electric power from hot water geothermal resources--the flash-steam process. In that process, dropping the fluid pressure results in a transfer of energy from a majority fraction of the fluid to a much smaller fraction of the fluid, resulting in that smaller fraction having a greatly increased enthalpy (and hence, quality).

Several survey-type studies of industrial utilization of geothermal fluids have recently been published. Howard (1976) edited a broad study of this type of general application to the United States. Bodvarsson, et. al., (1975) studied the Pacific Northwest region of the United States in a modestly-financed effort. Hornburg (1975) performed a careful study of the application of geopressured geothermal fluids to the pulp and paper and to the sugar processing and refining industries in Texas and Louisiana.

No work dealing with beneficiation of geothermal fluids is known (by this author); a similar idea using solar-derived, low-pressure steam was briefly discussed by Gyftopoulos (1974). A following section outlines some preliminary studies of geothermal fluids beneficiation, emphasizing the energetic, economic, and applications impacts that the proceedure could have on industrial utilization.

C. SURVEY OF POTENTIAL INDUSTRIAL UTILIZATION IN SOUTH TEXAS

Early in this study of the industrial utilization of geopressured geothermal fluids a survey approach was developed. As potential resources were known to exist in certain South Texas counties--Brooks, Cameron, Hidalgo, Kenedy, Kleberg, Nueces, San Particio, and Willacy-- a literature and field study was conducted to pinpoint possible industrial uses. Owing to the demographic distribution, two specific subregions can be selected for study as the remaining areas are rural and sparsely populated. The two subregions are the Rio Grande Valley and Corpus Christi region.

THE RIO GRANDE VALLEY

South Texas' Rio Grande Valley is an elongated zone of irrigated agricultural land situated along the north side of the Rio Grande River. As noted elsewhere in the Phase 0 report, this subregion is undergoing change from a wholly agricultural economic base to one in which tourism and industry are becoming of ever-increasing importance. Current industry in the area consists of agricultural and fisheries products processing, fertilizer preparation; oil and gas production; chemicals, plastic and rubber products manufacture; ship building and scrapping; mineral beneficiation; electronic assembly; electrical switchgear manufacturing; clothes manufacturing; busbody manufacturing; and packaging products finishing.

Industry in the eastern (Gulf of Mexico shore) area of the Valley is clustered in and about the Port of Brownsville area. The major energy consumption industry there is the Union Carbide Corporation Plastic and Chemical Division's Brownsville Plant. The plant produces mainly acetic acid, acetic anhydride, and formic acid along with a number of minor volume byproducts. Superheated steam is used to generate plant electricity, to heat distillation columns, and to run turbine drives for pumps and compressors. Lower enthalpy saturated steam is used for process heat for saltwater desalination in the preparation of boiler feedwater and process water. The plant is switching from natural gas firing to residual oil firing; certain waste products are being evaluated as supplemental boiler fuels.

Other industry in the port area includes a ship scrapping facility, a barge and ocean platform fabrication facility, three fluorspar beneficiation and pelletizing facilities, fishery and agricultural products processing (freezing), and cold storage facilities. In general, energy requirements are dispersed, low volume, or very high grade and thus not well matched to geothermal resources. An exception is the freezing and cold storage sector which, though dispersed, might provide sufficient load to justify a geothermal-based operation using absorptive cooling or steam turbine-driven refrigeration. Perhaps two to three megawatts (electric) equivalent of load could be aggregated for freezing and cold stores.

An oil refinery has been proposed for the Port of Brownsville. Although still in its early stages, this development, if successful, could add a substantial load requirement. It is contingent on dredging the channel and part of the port to deepen both to 42 feet. The remaining industries--switchgear, busbody manufacturing, electronic assembly, and clothes manufacturing--do not provide a sufficient quantity of load to be attractive.

Resource assessment currently indicates that discovery of geopressured geothermal resources of sufficient production is less likely in the immediate vicinity of the Port of Brownsville. However, should adequate fluids be discovered in the vicinity of the port, adequate utilization will be available.

Elsewhere in the Rio Grande Valley, energy requirements are dispersed except in the vicinities of McAllen, Harlingen, Edinburg, Alamo, and Weslaco. Each of these urban centers has one or more major industries. Southern Frozen Foods, Inc., near Alamo has both Individual Quick Freeze (IDF) blast tunnels at -40°F and a large cold store. Tex. Sun, Inc., at Weslaco produces and stores frozen citrus juices; Griffin and Brown at McAllen processes strawberries and other products (as well as provides cold storage warehousing); and Parker Seal Company at McAllen has a base load water chilling requirement (for rubber molds) of about 420 tons of refrigeration capacity.

Other potential utilization, in addition to that discussed above, could be in district heating and cooling. Communities such as McAllen, Harlingen, Edinburg, Alamo, and Weslaco provide user communities for this utility-type operation. Pan American University at Edinburg probably has sufficient conditioning load to justify a system dedicated for that institution's sole use.

Judging from the general design of the lithium bromide absorptive air contitioning system of the Rotorua International Hotel at Rotorua, New Zealand (Reynolds, 1970), about 120 tons of refrigeration can be derived from 100 gallons per minute flow of 300°F water. If one assumed a 1,500 GPM well, approximately 1,800 tons of conditioning would be continuously available. If storage capability were provided and five tons of refrigeration capacity (peak) allotted per 2,000 square foot housing unit, approximately 300 to 350 houses could be served at peak load conditions depending upon housing dispersion, losses in storage system, and losses in distribution system. In addition, hot water heating continuously and space heating in winter can provide load levelling and lower temperature (< 200°F) energy recovery from goethermal brine effluent from heat exchangers.

A significant problem in all of the Rio Grande Valley is availability of water. The Rio Grande resources allocated to the U.S. are fully committed so that additional water must be obtained from outside the region. Hence, self-desalination of geothermal brines or use of geothermal heat to desalinate brackish water will be of interest. Two essential elements must be present: favorable geothermal fluid production rates to provide low-cost fuel and favorable desalination plant economics.

As of 1970, seawater-desalination (multi-stage flash,10 MGD) was estimated to cost $0.88/1,000 gallons distributed as follows:

(a) Capital plant - $0.31/1,000 gallons (5 3/8% interest rate)

(b) Operations and maintenance - $0.15/1,000 gallons

(c) Fuel (@ $0.50/million Btu) - $0.42/1,000 gallons

Estimated costs in 1976 will differ greatly from those estimated in 1970. If one assumes no technology improvements have developed which drastically alter capital costs, the fact is that interest rates have gone from 5 1/2% to 8 - 9%, that inflation since 1970 has been about 50%, and that fuel prices have risen from $0.50 to $2.00/million Btu. Thus, a gross estimate of costs might be:

(a') Capital - $0.70/1,000 gallons

(b') Operations and maintenance - $0.23/1,000 gallons

(c') Fuel (@ $2.00/million Btu) - $1.68/1,000 gallons

The total cost estimate is roughly $2.61/1,000 gallons. This price is not competitive with any traditional source of supply. Note, however, that the <u>fuel</u> component dominates. A geothermal well producing 300°F fluids as supply to a desalination unit might produce heat at a cost of $1.10/million Btu (when rejecting brine at 160°F and being operated by a municipality).

Therefore, the geothermal brine-fueled desalination unit might produce desalinated water at the estimated price of $2.03/1,000 gallons. (Note: no methane credit has been taken.) With a methane credit of $2.17/million Btu for saturation methane content at 300°F, a brine fuel price of $0.50/ million Btu is estimated and the estimated price of desalinated water becomes $1.43/1,000 gallons. This price is still quite high. Taking the cost for distribution as $0.15/1,000 gallons, the total tap cost would be $1.58/1,000 gallons. This price is 200 - 300% higher than the average price charged by municipalities in South Texas. As a comparison, a residence using 10,000 gallons per month in Corpus Christi would be billed $5.50 ($0.55/ 1,000 gallons, first 20,000 gallons), in Kingsville $7.70 ($1.18/1,000 gallons, first 3,000 gallons; $0.60/1,000 gallons thereafter), and in McAllen, $7.85 ($2.00 for first 2,000 gallons; $0.50/1,000 gallons for next 5,000 gallons; $1.45/1,000 gallons for succeeding 5,000 gallons).

Resource assessment has identified the existence of geopressured geothermal fluids in Hidalgo and western Cameron Counties. However, the production of these fluids presents a significant problem already well known, but not solved by the oil and gas industry. Porosities and permeabilities of these far South Texas reservoirs are considered to be too low for geothermal fluids production at rates (~ 40,000 BBL/day) which would be economic. Thus, an inexpensive method for stimulating deep geopressured goethermal production from low permeability formations will be essential before significant industrial utilization will develop in the Rio Grande Valley area unless better permeability reservoirs, atypical of those sought for oil and gas production, can be found.

CORPUS CHRISTI REGION

The region about Corpus Christi is an important industrial and agricultural district comprising all or parts of four counties: Aransas, Kleberg, Nueces, and San Patricio. One large geothermal fairway area is located in the region; this fairway area stretches from the southern end of Copano Bay through the upper Corpus Christi Bay and Nueces Bay areas and to the southwest of Corpus Christi. Industry in the area includes at least five chemical plants consuming approximately 60,000 x 10^9 Btu annually; five petroleum refineries consuming approximately 50,000 x 10^9 Btu annually while refining approximately 19,000,000 tons annually; and two metals refining operations consuming approximately 53,000 x 10^9 Btu per year smelting aluminum and zinc.

The Port of Corpus Christi has plans for dredging the port area and the ship channel to accomodate deep draft shipping. This planned port improvement is expected to lure raw materials tonnage and to lead to expansion of industrial activity in the Corpus Christi region. Thus, not only does this region comprise a significant existing energy consumption market, but, in addition, offers prospect for market growth and a unique opportunity for industrial use of geothermal energy.

The unresolved issues for the Corpus Christi fairway and industrial utilization are the specific location of the resource, the producibility and quality of the resources, and the processes in refinery and chemical plant to which geopressured geothermal fluids may be applied. More than 50 chemical, petrochemical, and fuel refining processes are in use in Corpus Christi industry, and each of these has varying process heat requirements. Some of these processes provide significant energy recovery for use in other processes or elsewhere in the same process.

Most chemical, petrochemical, and petroleum refining processes are proprietary so that specific details of the quantities and grades of heat required are not readily available. It is known, however, that some distillation trains and other processes can make ready use of process steam of 600°F. Of course, normal geothermal fluids cannot produce 600°F process steam. One is lead to consider methods for beneficiating geothermal fluids. Without beneficiation, the majority of petroleum refining, petrochemical, and chemical process heat requirements cannot be met by geothermal fluids. Without beneficiation, only crude heating, feedstock heating, and feedwater heating are amenable to direct geothermal fluid application.

D. SULFUR FRASCHING - A POTENTIAL DIRECT UTILIZATION OF GEOPRESSURED GEOTHERMAL FLUIDS

1. The following survey of sulfur Frasch mining on the United States Gulf of Mexico coast places the industry in the context of world and U.S. sulfur production industry. Prospects for the Frasch industry and its production economics are reviewed with respect to the growing regulation-required production of elemental sulfur as a byproduct of desulfurization of fossil fuels. The potential impact that direct use of fluids or heat from geopressured geothermal resources might bring to the Frasch sulfur industry are discussed in a preliminary fashion. Conclusions concerning a future application of geothermal energy are presented.

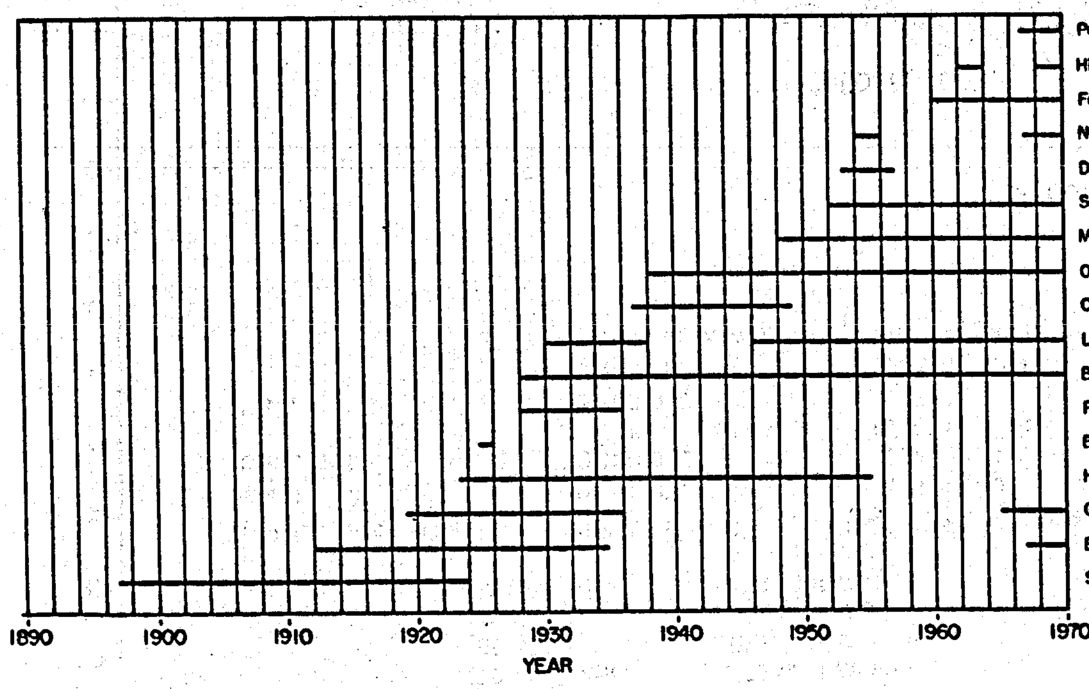
2. THE ROLE OF FRASCHING IN THE SULFUR INDUSTRY

The Frasch process was invented in 1894 by Dr. Herman Frasch. This method was first successfully used by the Union Sulfur Company at Sulfur Mine, Calcasieu Parish, Louisiana, where in 1895, sulfur was obtained commercially from the cap rock of a buried salt plug. The Frasch method was employed next in Texas where sulfur mining at Bryan Mound, Brazoria County, commenced in 1912. The chronology of sulfur mining in Texas is shown in Table VII-1. Thd Frasch mining method was important in the development and production of sulfur not only from salt plugs of the Texas Coastal Plain, but also from similar occurrences in Louisiana and Mexico. Some of the mining operations in Louisiana are offshore in the Gulf of Mexico. Frasch mining has also commenced in West Texas in Pecos and Culberson counties. The method is also used in Iraq and Poland.

Sulfur valued at $130,977,075 was produced in the state of Texas during 1968. This was second only to the value of oil and gas produced in Texas that year. Total sulfur production in Texas from 1924 to 1967 represents 68 percent of the elemental sulfur produced in the United States and 38 percent of the world production for these years. The major portion of the sulfur produced in Texas is produced by the Frasch process as can be seen in Figure VII-1. The Frasch method also contributes heavily to the Free World's production of sulfur (see Figure VII-2).

TABLE VII-1

CHRONOLOGY OF FRASCH SULFUR MINING IN TEXAS*



	Accumulated production to Jan. 1, 1968 in long tons
Pecos County, Duval and Sinclair	190,402
High Island, Pan Am. & U.S.	36,788
Fannett, Texas Gulf Sulfur	1,942,607
Nash, Freeport	208,059
Damon Mound, Standard Sulphur	140,000
Spindletop, Texas Gulf Sulphur	6,854,393
Moss Bluff, Texas Gulf Sulphur	5,272,576
Orchard, Duval	5,245,345
Clemens, Duval	2,975,828
Long Point, Texas Gulf Sulphur	5,218,309
Boling (New Gulf), Texas Gulf Sulphur	63,189,892
Palangana, Duval	236,622
Big Creek, Union Sulphur	1,450
Hoskins, Freeport	10,845,090
Gulf (Big Hill), Texas Gulf Sulphur	12,562,519
Bryan Mound, Freeport	5,002,688
Sulphur Mine, Louisiana, Union Sulphur	9,400,000

*After Hawkins and Jirik (1966), Haynes (1959), Myers (1968a, 1968b), Zimmerman and Thomas (1969), and Oil and Gas Journal (July 22, 1968).

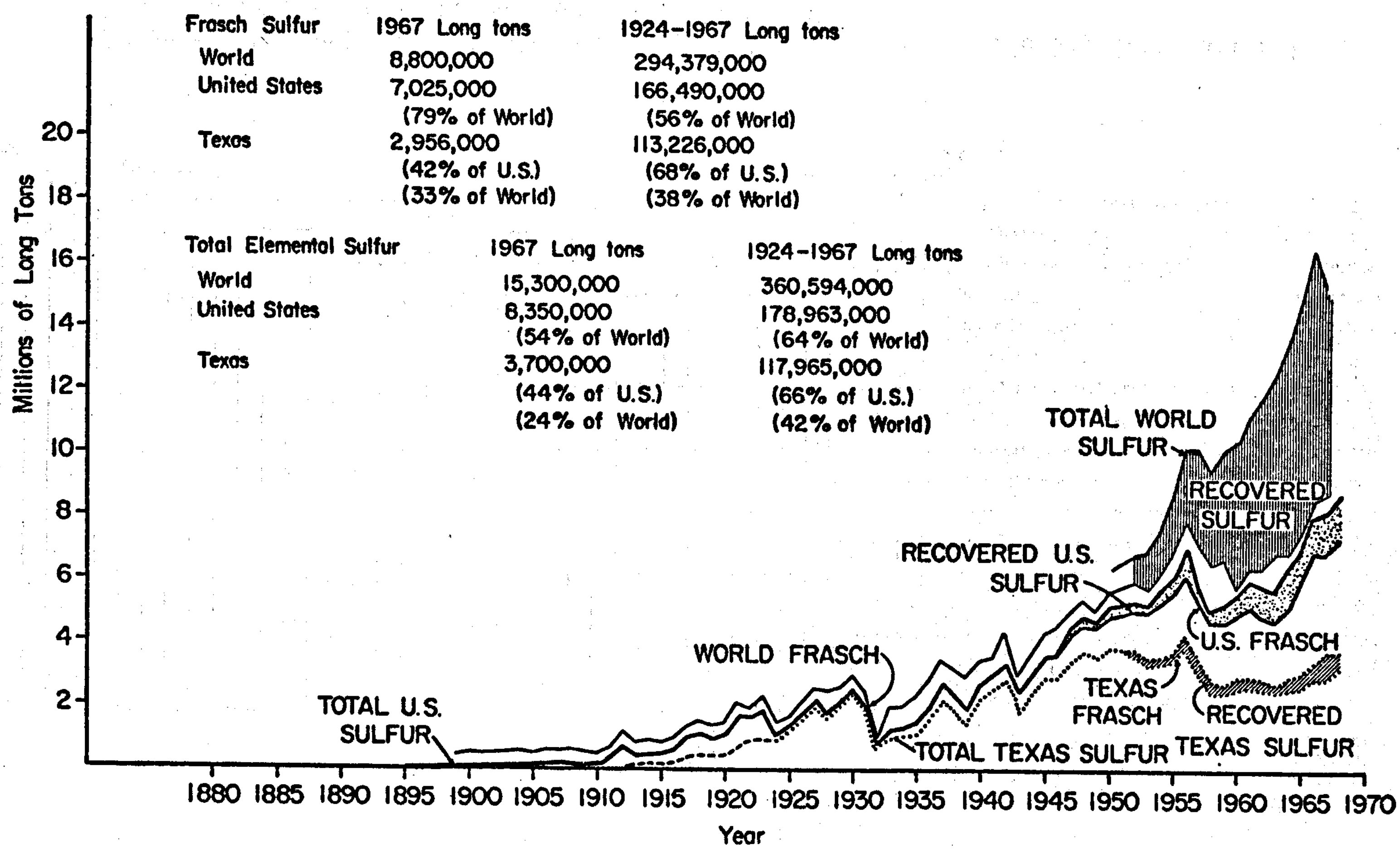


Figure VII-1: Sulfur production of Texas, the United States, and the world.

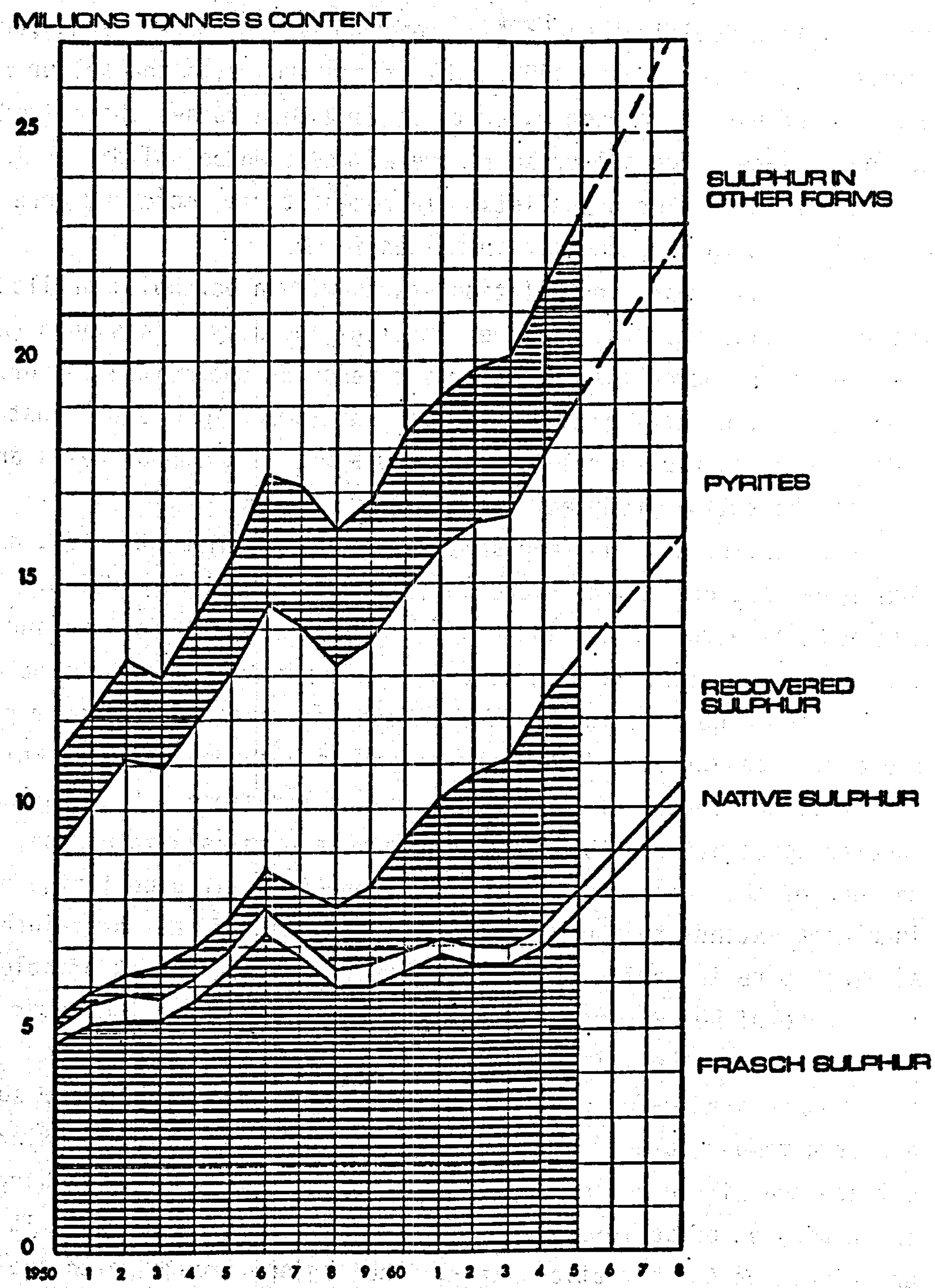


Figure VII-2: Free-world sulfur production.

3. THE FRASCH PROCESS

The method of operation of a sulfur mine in the Gulf Coast sulfur deposits is a modification of the process devised by Dr. Herman Frasch, and perfected commercially in 1903. This technique melts the sulfur while it is underground by pumping hot water to it, and then raises the melted sulfur to the surface. The sulfur so recovered may then be solidified in vats or in the form of flakes or pellets. In recent times, more and more of it is being shipped to the consumer in molten form.

A typical Frasch installation starts with a borehole, drilled by a rotary rig like that used in the petroleum industry. This hole (well) is used for introducing the hot water and removing the molten sulfur. Central pumping stations equipped with valves, meters and gauges are installed to control and distribute water, steam and air to a group of wells and to collect the sulfur produced.

Each sulfur well has the same underground equipment, i.e., a nest of four pipes set one inside the other, as shown in Figure VII-3. The outermost pipe is eight or ten inches in diameter and goes down to and rests on top of the cap rock. Inside is a six-inch pipe which extends below the first pipe through the limestone-sulfur strata and rests on the upper portion of the barren anhydrite. Inside the second is a three-inch pipe which extends almost to the bottom of the sulfur bearing limestone. A collar seals the annular space between the three-inch pipe and the six-inch pipe, just above the end of the inner pipe. Finally, a one-inch air pipe inside of the three-inch pipe extends to a depth just above the end of the three-inch pipe. The six-inch pipe is perforated at two levels. The upper set of holes permits the escape of hot water into the sulfur formation, and the lower set permits the entrance of the molten sulfur.

Superheated water under pressure of 125 to 200 pounds per square inch and at a temperature of 320°F to 330°F is forced down the annular space between the six-inch pipe and the three-inch pipe and is discharged through the upper set of perforations into the porous formation where it mixes with and displaces the formation water. The region through which the hot water circulates is heated to a temperature above the melting point of sulfur. The liquid sulfur, being heavier than water, makes its way downward, forms a pool, displaces water around the foot of the well, and enters the well

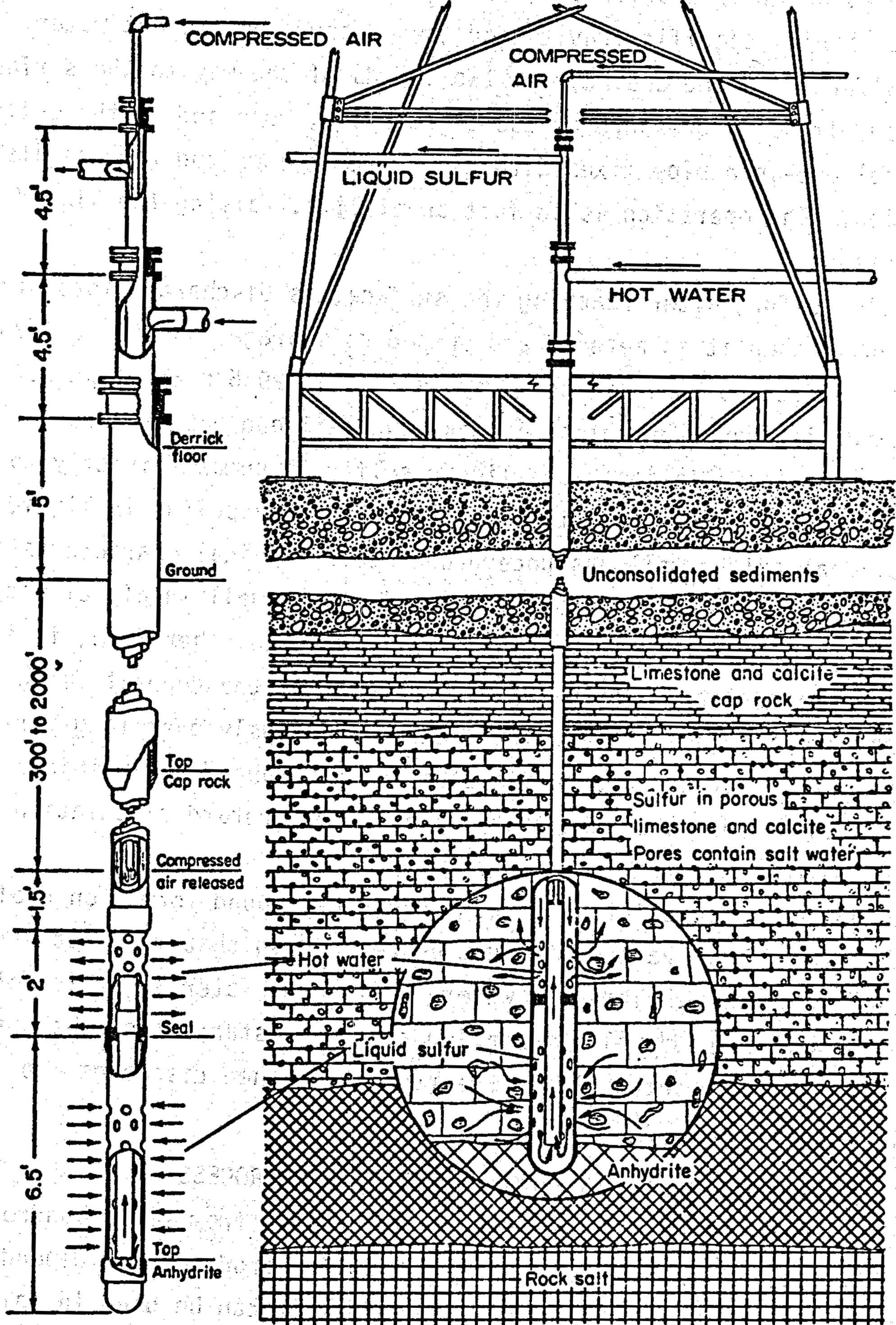


Figure VII-3: Frasch mining method. From Texas Gulf Sulphur Company (1957, p.10). Copyright 1967 by Texas Gulf Sulphur Company. Permission to reporduce granted by the company.

column through the lower perforations of the six-inch pipe. It then rises in that pipe as water-free sulfur. The height to which the sulfur rises is determined by its specific gravity and the pressure of the hot water. The molten sulfur is forced one half or two thirds of the way to the surface. Compressed air, at a pressure of 500 to 600 psia, released at the bottom of the central one-inch pipe mixes with the sulfur column and reduces its weight by aeration. The operation is in fact an airlift, raising the liquid sulfur to the surface.

Liquid sulfur, after reaching the surface, is discharged into steam-heated tanks; then it is metered and pumped to storage vats to cool and solidify. Sulfur obtained in this way is usually 99.5 percent pure. The solid sulfur is loaded on ships, barges, and railroad hopper cars for shipment. At some installations, the liquid sulfur is pumped directly to heated and insulated ships or barges that can transport the sulfur in liquid form.

The ideal sulfur well has underground topographical characteristics which permit circulation of the hot water from the well in all directions, and the return flow of molten sulfur. Well location, therefore, is influenced by local characteristics in the particular part of the deposit being mined. Wells that are favorably located produce continuously over long periods. Some may last a year or more, while others may be abandoned within a few weeks because denseness of the rock formation may retard circulation of hot water and molten sulfur.

The hot water percolating through the underground formation cools as it melts the sulfur. Part of it must be removed so that more hot water can be forced underground. The cold water, or "bleed" water as it is called, is removed through "bleed" wells installed at some distance from the operating wells. It is pumped into holding reservoirs and then discharged to disposal ditches or canals.

4. ENERGY REQUIREMENTS AND ECONOMICS OF FRASCH PROCESS

The amount of hot water needed varies widely, from seven hundred to twelve thousand gallons per single ton of sulfur produced and depends on the deposit and skill of the operator. Before it can be used in boilers or mine water heaters, the water usually must be treated or softened to remove scale-forming and corrosive substances which are damaging to boilers, heaters, and pipes.

The boilers normally operate on natural gas, but may be equipped to permit a change to fuel oil. The steam produced in the boilers is used to heat the water for mining as well as to maintain the sulfur in molten condition while it is being pumped to the storage vats. The steam may also be used to generate electricity to operate the plant's machinery, such as the air compressors which produce from 500 to 900 cubic feet of compressed air at 500 to 600 psia for each ton of sulfur produced.

Typical 1975 sulfur extraction costs were approximately $30.00 per long ton. Controllable costs of approximately $24.00 per long ton were: natural gas, $18.00 and plant equipment, $6.00. Some facilities produce more efficiently, but have higher plant capital and fixed costs while some facilities are less efficient and require more hot water and hence more natural gas.

Natural gas consumption for Texas and Louisiana Gulf Coast Frasch sulfur mining in 1975 is estimated as 28.0×10^6 to 35.0×10^6 MCF. Approximately 80 to 85% of this natural gas was used to heat injection water. Natural gas costs amounted to approximately 70% of total costs and, consequently, any significant reduction in natural gas usage will significantly reduce the operation's expenses. This is true for most, if not all, of the sulfur Frasching operations on the Gulf Coast: a significant reduction in natural gas usage means a significant reduction in total expenses.

5. EXISTING FRASCH OPERATIONS IN TEXAS AND LOUISIANA

Approximately 70 domes have been evaluated along the Texas and Louisiana Coast as potential sources of Frasch sulfur. At present, 9 of these domes are being exploited. There are some 4 domes probably capable of being reactivated and some 10 other domes that may possibly be exploited in the future. See Figure VII-4 for the location of some of these domes. Also, some 10 to 12 off-shore domes have been prospected for sulfur. The following is a brief description of the operational domes. Production figures, hot water/sulfur ratios, and estimates of recoverable reserves may be obtained from Table VII-2.

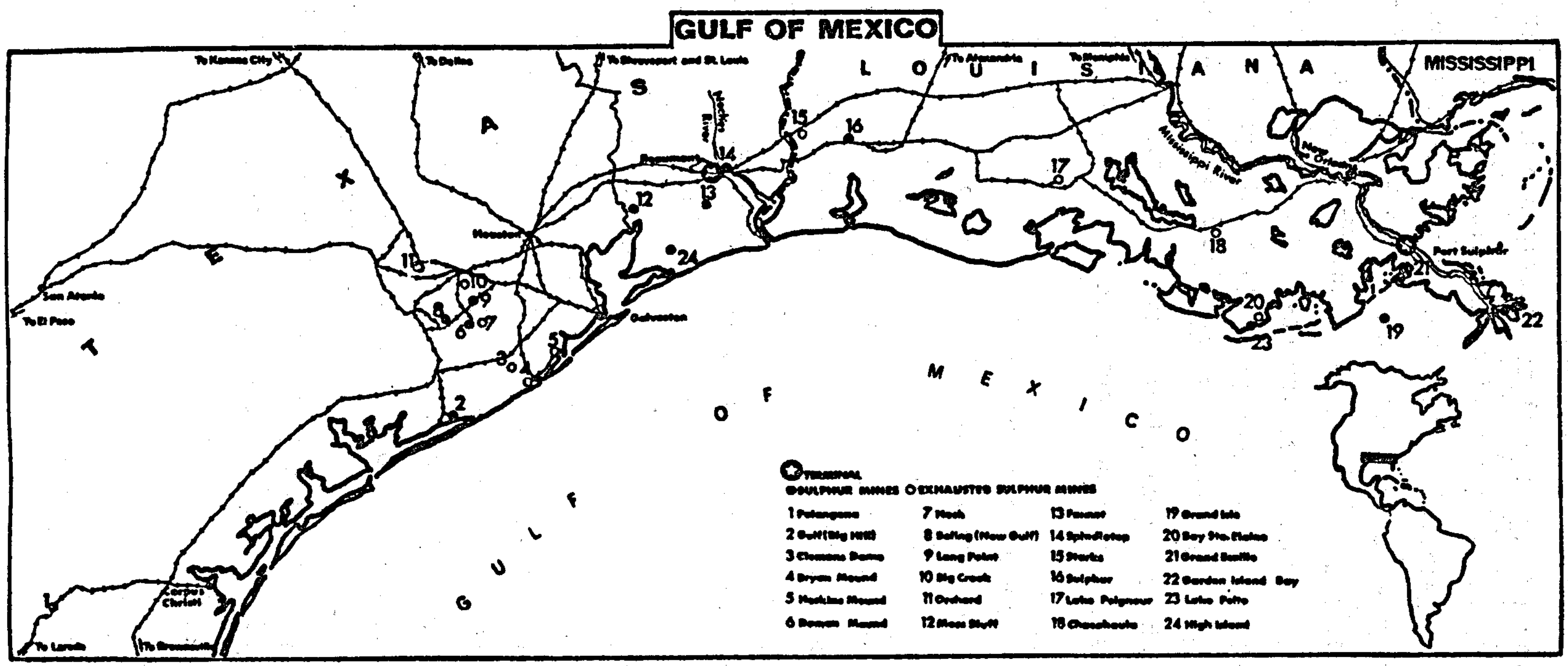


Figure VII-4: Location of sulfur resources, Gulf of Mexico Basin.

TABLE VII-2

ESTIMATED PRODUCTION HOT WATER/SULFUR RATIOS
AND RECOVERABLE RESERVES - SELECTED FRASCH MINES*

PLANT	PRODUCTION FIGURES (LONG TONS)			
	1963	1964	1965(est.)	1975(est.)
Boling Dome	1,191,000	1,148,000	1,250,000	952,000
Long Point Dome	234,000	251,000	280,000	308,000
Moss Bluff	215,000	217,000	250,000	212,000
Fannett	178,000	143,000	180,000	144,000
Spindletop	464,000	532,000	500,000	100,000
Grand Ecaille Dome	1,153,000	1,279,000	1,300,000	-
Grand Isle Dome	552,000	635,000	1,100,000	-
Garden Island Bay	396,000	452,000	700,000	-
Lake Pelto Dome	367,000	374,000	500,000	-

PLANT	HOT WATER/SULFUR RATIOS: (GALLONS/LONG TON)	ESTIMATES OF RECOVERABLE RESERVES: (LONG TONS)	
		MINIMUM	PROBABLE
Boling Dome	3,650	20,000,000	35,000,000
Long Point Dome	5,200	-	2,000,000
Moss Bluff	6,000-8,000	3,000,000	8,000,000
Fannett	-	-	2,000,000
Spindletop	5,240**	7,000,000	12,000,000
Grand Ecaille Dome	1,000-1,700	12,000,000	22,000,000
Grand Isle Dome	1,800	10,000,000	20,000,000
Garden Island Bay	2,000	7,000,000	17,000,000
Lake Pelto Dome	-	-	-

*Published analyses of many of these factors are estimates and actual detailed figures are usually classified company matter.

**This hot water/sulfur ratio is based upon 1974 production figures. The remaining ratios are based upon the most recent production estimates given above.

5.1 BOLING DOME

Location: Newgulf, Texas

Operating Company: Texas Gulf Sulphur Company

The largest sulfur dome in the world, Boling has been under continuous exploitation by Texas Gulf Sulphur Company since March 20, 1929. Water from the San Bernard River is pumped into a 260-acre reservoir which has a capacity of 700 million gallons. This supply is supplemented by water from wells. The hot process lime-soda water softening plant at Newgulf is one of the largest of its kind in the world and has treated successfully more than 30,000 tons of water in a single day.

The power plant at Newgulf consists of ten watertube boilers of the Stirling type, each with a rating of 1,560 horsepower. They operate normally on natural gas, but are equipped to permit an almost instantaneous change-over to fuel oil if, for any reason, the gas supply is interrupted. Another safeguard against a possible fuel shortage is in the design of the boiler settings whereby, if neither gas nor oil is available, the necessary equipment for burning powdered lignite can be installed. Economizers recover practically all of the heat of the stack gases. Other equipment in the power plant includes turbogenerators for producing electricity; compressors to furnish air at 500 to 600 pounds pressure for lifting the liquid sulfur in the wells to the surface; and instruments for regulating operating efficiency.

Bleedwater is discharged into the Lone Star Salt Water Company ditch, thence into the San Bernard River, Segment 1301, all in the Brazos-Colorado Coastal Basin. The Texas Water Quality Board has placed the following limits on the discharge: not to exceed an average of 12,500,000 GPD, not to exceed a maximum of 15,000,000 GPD.

Deliveries from Newgulf comprise solid bulk and liquid sulfur. The bulk of deliveries of liquid and solid sulfur is by rail, a small proportion direct to users, and the greater part to the shipping terminal at Beaumont, Texas. The Beaumont, Texas, shipping and storage terminal is situated on a turning basin with 40 ft. draft and access to the Neches River some 30 miles from its mouth on the Gulf of Mexico. There are three jetties. Each is capable of accomodating ocean-going vessels.

5.2 LONG POINT DOME

Location:	Three miles south of the intersection of FM 1994 and FM 762 in Fort Bend County, Texas
Address:	Route 1, Box 126 Needville, Texas 77461
Operating Company:	Jefferson Lake Sulphur Company, a subsidiary of Occidental Petroleum.
Plant Manager:	Mr. Cecil Powell

Jefferson Lake Sulphur Co. in 1940 took over the sulfur rights on a royalty basis to 675 acres of this dome and started regular production in 1946. The productive dome area is reported to extend over 500 acres, the cap rock to be 150 feet thick and sulfur bearing ores to be situated at a depth of 700 - 1,000 feet. On other parts of the dome unsuccessful operations were abandoned by National Lead Co., Lone Star Sulphur Co. in 1959, and Admiral Sulphur Co. in 1956.

Current planned production rate is about 300,000 long tons annually. Twelve to thirteen mcf of natural gas are burned daily to heat 4.4 million gallons of treated groundwater to 328°F. (Groundwater comes from nearby shallow sands.) Part of the water is used to produce steam to drive equipment such as electrical generators which supply all of Long Point's power. The remainder is pumped to about 15 production wells. Only 6 of the 13 Frasch mines in Texas and Louisiana are more efficient than Long Point, but those 6 mines produce 85% of the total Frasch-mined sulfur. It is estimated that 75% of Long Point's controllable costs are for natural gas. 1975 non-controllables are estimated as $6.25 per long ton.

The current optimum rate of bleedwater production ranges from 1.9 to 2.3 million gallons per day. From the bleedwells the wastewater is routed to 3 holding ponds which have approximately 500 acres of surface area and contain a maximum of four feet of water. The holding ponds are designed with a capacity to retain the wastewater generated during 12 months production of sulfur.

The quality of wastewater may change from time to time, depending on its point of collection within the bleedwell system and its retention time in the ponds. The concentration of chloride is generally 40,000 mg./1. The concentration of calcium sulphate is close to the saturation point. Approximately 200 ppm of H_2S is present. The temperature of wastewater within the system varies from 100 to 130 degrees. From the ponds, the water is discharged into Big Creek; thence to the Brazos River, Segment 1202 in the Brazos River Basin. There are 3 gates of discharge. The Texas Water Quality Board requires that the discharge not exceed a maximum of 938,400,000 gallons per year during a total discharge time per year of no more than 192 hours. Both Big Creek and the Brazos River must be at flood stage during release of wastewater. There is no treatment prior to discharge.

5.3 MOSS BLUFF

Location: FM 563 at intersection of Chambers-Liberty County line, approximately 14 miles south of Liberty, Liberty and Chambers Counties, Texas.

Operating Company: Texas Gulf Sulphur Company

Plant construction at this dome, held up by World War II, began in 1947 and production started in June 1948. The entire output is transported by barge to the Beaumont terminal and storage.

Intake of water is 4.65 MGPD from a surface water body. The temperature of this water in winter ranges from 40°F to 75°F and in summer from 75°F to 100°F. Boiler feed water is 1.30 MGPD and process water is 3.45 MGPD. The water is treated prior to heating. The wastes involved in this process are the result of operation of the water heating plant associated with the Frasch process. Sludges from the water treating plant are used for drilling mud. Continuous blowdown from the boilers is used to treat mine water. Sanitary wastes are reused for mine water. Cooling water is a closed system, thus no blowdown. Wastes involved are primarily due to zeolite softener regeneration with a small amount of pump gland water and wash water.

Bleedwater flows from wells to settling basins thence to two oxidation ponds operating in series, then is discharged. The water is discharged into the Tidal Zone of the Trinity River. The Texas Water Quality Board requires that this discharge not exceed an average of 4,500,000 GPD and not exceed a maximum of 20,000,000 GPD. A disposal problem may arise upon the completion of Wallisville Dam.

5.4 FANNETT

Location: Approximately 3 miles southwest of the intersection of State Highways 124 and 365 near Fannett, Jefferson County, Texas.

Operating Company: Texas Gulf Sulphur Company

Production at Fannett dome started in May, 1958. The entire output is carried by road in liquid form to the Beaumont, Texas terminal (see Boling dome). The bleedwater is discharged to Taylor Bayou, Segment 0701, in the Neches-Trinity Coastal Basin.

5.5 SPINDLETOP

Location: State Highway 347 approximately 1 mile south of Beaumont, Texas.

Operating Company: Texas Gulf Sulphur Company

Operations started in May 1952. Boiler capacity is 4 million gallons per day. The dome is adjacent to Texas Gulf's Beaumont terminal. Vat and liquid storage for the dome production and for the terminal are common.

The plant intakes 7,375,000 GPD. See Figure VII-5 for detailed usage. The water used for the mining operation is heated to 330°F. Both the water used for steam generation and mine water is conditioned. The water conditioning process consists of treating raw Neches River water obtained from the Lower Neches Valley Authority with clarification, filtration, zeolite softening, and deaeration.

Formation water removed from the dome is treated in a waste treatment plant. The process consists of reacting the soluble sulphides with sulfurous acid under controlled pH conditions. The soluble sulfides are converted to elemental sulfur and soluble oxidized sulfur compounds. At the end of the process, the pH is adjusted. The elemental sulfur is removed in a thickener and settling ponds. The settled sulfur sludge is unsalable and is injected into the dome in an exhausted area. The water is discharged into the Neches River, Segment 0601 of the Neches River Basin. The Texas Water Quality Board requires that the discharge not exceed an average of 5,900,000 GPD and not exceed a maximum of 8,000,000 GPD.

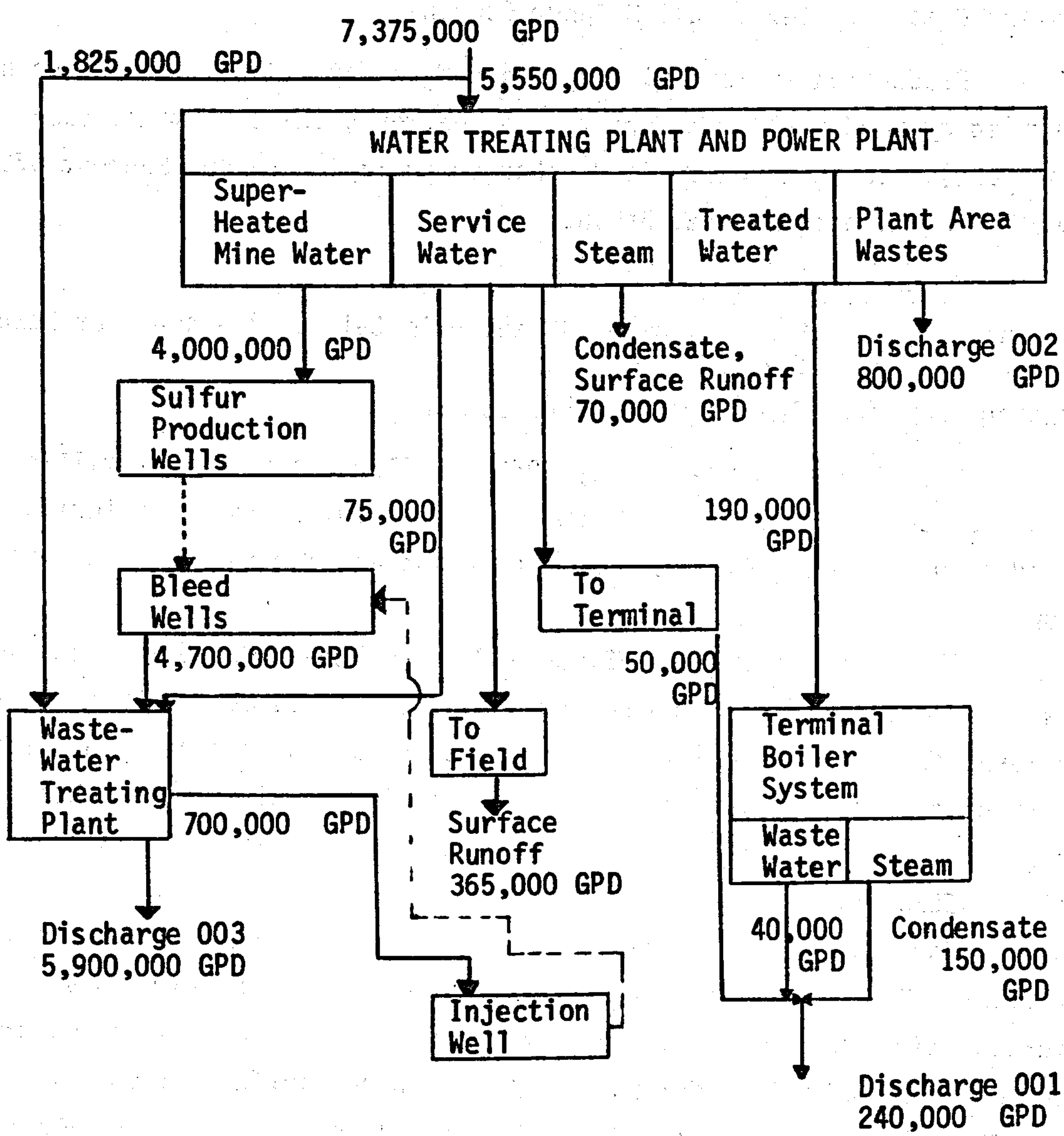


Figure VII-5: Approximate water flow diagram for Spindletop. (Texas Water Quality Board)

5.6 GRAND ECAILLE DOME

Location: 10 Miles west of Port Sulphur, 45 miles south of New Orleans.

Operating Company: Freeport Sulphur Company

Production started in 1933. Freeport Sulfur Company's largest sulfur dome deposit, this dome has to date contributed about one-fifth of the total sulfur extracted from dome formation by the Frasch process. Boiler capacity is 6¼ million gallons per day. The dome is reported to have one of the most favorable hot water/sulfur ratios. The plant output is carried in liquid sulfur barges along a 10 mile canal to Port Sulphur, the company's centralized storage point for solid and liquid sulfur. The port accomodates two ocean-going vessels. Depth is stated to be 40 feet.

5.7 GRAND ISLE DOME

Location: Block 18. 7 miles off Louisiana shore.

Operating Company: Freeport Sulphur Company

Production at this submerged dome, which is beneath 50 feet of water, started in April 1960. Operations are effected from a Y shaped steel platform which is 75 feet above sea level. Power and boiler plants, the latter heating sea water utilizing a technique evolved by Freeport Sulphur Company engineers, are installed at one end of the platform some 2,000 feet distant from the dome formation in which sulfur bearing ores are beneath the cap rock at about 1,700 feet. Based on fixed drilling platforms, flexibility of operation is achieved by means of directional drilling of producing wells.

The boiler plant has an average capability of 5 million gallons per day. The output is pumped in liquid form through a heated pipeline laid in a trench along the ocean floor to the mainland where it is loaded into tank barges and carried in liquid form 25 miles to Port Sulphur.

5.8 GARDEN ISLAND BAY

Location: Mississippi Delta

Operating Company: Freeport Sulphur Company

Production started in November, 1963, the U. S. sulfur industry's largest project since the establishment of Boling Dome and Grand Ecaille Dome.

Housed in a plant built some 16 feet above ground level and set on piles, boiler capacity is 3.5 million gallons per day and is designed to operate normally at 3 million gallons per day supplying 10 - 12 wells. Water supplies are drawn from a 600 acre reservoir, holding 1,500 million gallons, which is filled with comparatively sweet water. The entire output is carried in liquid form in barges to Port Sulphur.

5.9 LAKE PELTO DOME

Location: 60 miles southwest of New Orleans on a man-made island on the Louisiana shore.

Operating Company: Freeport Sulphur Company

The dome which Freeport Sulphur Company has leased from the Texas Company lies under 8 feet of water on the edge of the foreshore. The boiler and power plants are barge mounted. The barge was sunk into place. The boiler plant is capable of using salt water. Exploitation started in November, 1960.

6. POSSIBLE FUTURE FRASCH OPERATIONS

6.1 GULF DOME

Location: 20 miles southeast of Bay City, Matagorda County, Texas.

Operating Company: Texas Gulf Sulphur Company

Operations were suspended in September of 1970. At that time, Texas Gulf Sulphur indicated that the mine would be reactivated when market conditions permitted. There remain reserves of probably a million tons. Output is moved by rail in liquid form to Beaumont (see Boling Dome). There are separate boiler and compressor plants for each well.

6.2 DAMON MOUND

Location: 20 miles south of Rosenburg, Texas.

In November, 1953, Standard Sulphur Company installed a mobile boiler and power plant with a capacity of $^1/_4$ million gallons of water. About 140,000 tons of sulfur were extracted in the following 3 years. The plant closed down in 1957. This dome is believed to contain recoverable sulfur reserves of probably $^1/_2$ to $^3/_4$ million tons.

6.3 HIGH ISLAND DOME

Location: Galveston County, Texas

At present unexploited. During 1960-1961 United States Sulphur Corp. exploited the dome and extracted some 37,000 tons brimstone, having installed a boiler plant with a daily capacity of 1.5 million gallons. This was severely damaged by Hurricane Carla in 1961. No plans to resume exploitation are known. Recoverable sulfur reserves are believed to be not less than $^1/_2$ million tons and possibly 2 million tons.

6.4 SULPHUR MINE

Location: Calcasieu Parish, Louisiana

Operating Company: Union Texas Petroleum Division of Allied Chemical Corp.

The first sulfur bearing salt dome to be exploited by the Frasch process. Although earlier operations ceased because of the failure to find further sulfur bearing strata, there remain along the flanks of the dome significant recoverable sulfur reserves which are estimated at not less than $^1/_2$ million and possibly as much as $1^1/_2$ million tons.

6.5. OTHERS

In addition, there are ten other salt domes in Texas which may prove productive of sulfur:

NAME	COUNTY
Allen	Brazoria
Hockley	Harris
Barbers Hill	Chambers
Big Hill	Jefferson
Blue Ridge	Fort Bend
Brenham	Washington
Gyn Hill	Brooks
Humble	Harris
Pierce Junction	Harris
South Liberty	Liberty

7. ENVIRONMENTAL PROBLEMS

The extraction of sulfur weakens the rock formation and subsidence may follow. This may break the pipes in the well and end productivity of the well. Subsidence may be desirable in mining even though wells may be lost as a result. The advantage of subsidence is that the volume of exhausted formation through which hot water can circulate is reduced. The crushed exhausted formation after caving is relatively impervious and confines the circulation of hot water to the more porous sulfur bearing parts of the deposit.

Recent practice is to inject specially selected muds to fill and seal off some of the areas already mined. Sludges from the water treatment plants and from the settling reservoirs used for bleed water are sometimes used for this purpose. If geopressured geothermal waters were injected directly into formations without prior treatment, drilling muds might have to be purchased. These muds reduce the need for increased hot water and lessen some of the dangers of collapse and subsidence.

Disposal of bleed water poses a problem for most Frasch operations. In Texas the Texas Water Quality Board monitors these discharges. The plants are assigned definite maximum allowable amounts of discharge per day and this limits (along with boiler capacity) maximum possible production. In some cases they are also required to have large holding ponds for these discharges.

8. FUTURE ECONOMICS OF THE SULFUR INDUSTRY

8.1 MARKET AND SUPPLY

For the next five years the price of sulfur will probably be determined by the most effecient Frasch operations on the Gulf Coast. However, the increased production of sulfur recovered from sour natural gas and oil, refinery gases, smelter flue gases, sulfur-bearing minerals other than native sulfur, and from coal and coal gases make the prediction of future sulfur prices extremely difficult, and some consideration has been given to setting a minimum selling price for sulfur.

8.2 ECONOMICS OF GEOPRESSURED GEOTHERMAL WATER USE IN FRASCH OPERATIONS

Factors that control a profitable Frasch mining operation include: quality (percent) of the sulfur ore, size of the ore body, depth of the ore body, recoverability of the sulfur, costs of exploration including drilling and assaying, drilling of production wells, water, heat, royalties to landowners, transportation, taxes, and market price. Published analyses of many of these factors are estimates and actual detailed figures are usually classified company matters.

Sulfur bodies averaging 12 to 16 percent have about 75 percent recoverability, and there are bodies with 20 percent or more sulfur which may have up to 85 percent recoverability. Sulfur deposits with 12 percent or higher quality are usually considered to be economically mineable if not too deep. Recoverability is also a consideration in calculating reserves, and the low-grade sulfur deposits are not considered as economically available reserves.

Exploration costs include the leasing and rental of the mineral rights of the land and the exploration drilling. Production costs are mainly concerned with the drilling of production wells, water, heat, and transportation. The cost of production wells depends upon the depth and the price of casing. Usually three to four wells are needed per acre. Water may cost from 40 to 70 cents per 1,000 gallons for purchase and treatment. However, much of this water can be retreated and re-used. Heat and power costs are extremely variable but are a significant part of the total cost in Frasch mining operations. Transportation is also variable depending upon the length of haul. Other costs include severance taxes in Texas. In addition, the sulfur industry pays federal income taxes, and state and county property taxes as well.

Heat and power costs are a direct result of the amount of natural gas used to fire the Frasch operation's boilers. If geopressured geothermal water can be supplied at around 320°F, then most, but not all, of the natural gas normally used in the heating of the water will not have to be purchased. With a future of increasing natural gas and fuel oil prices, these savings could be large indeed. Obviously, however, these savings will be offset by the costs of obtaining the geothermal waters. These costs will depend upon drilling and distribution costs which may prove to be considerable. Table VII-3 shows the amount of natural gas which might be saved on a plant by plant basis if 325°F can be supplied and thus eliminate the need for further heating of the water.

For many Frasch operations this saving of natural gas costs may prove the difference between being able to operate competitively with recovered sulfur operations or having to close down entirely. Table VII-4 presents a rough calculation of the economics of using 325°F geopressured geothermal fluids directly or indirectly in Frasch sulfur recovery operations.

TABLE VII-3

NATURAL GAS AND HOT WATER REQUIREMENTS FOR FRASCH SULFUR MINES

PLANT	HOT WATER/SULFUR (GALLONS/LONG TON)	NATURAL GAS USED (THOUSAND CUBIC FEET/TON)*
Boling Dome	3,650	8.5
Long Point Dome	5,200	12.0
Moss Bluff	6,000-8,000	13.9-18.5
Fannett	-	-
Spindletop	5,240	12.1
Grand Ecaille Dome	1,000-1,700	2.3- 3.9
Grand Isle Dome	1,800	4.2
Garden Island Bay	2,000	4.6
Lake Pelto Dome	-	-

*Table VII-3 shows the amount of natural gas used in heating the water required, per ton of sulfur produced, from 75°F to 325°F assuming a 90% efficiency.

TABLE VII-4

ESTIMATED ECONOMICS OF GEOTHERMAL FLUIDS UTILIZATION IN FRASCH MINING FOR SULFUR

A.	BASIC ASSUMPTIONS:	
	325°F Water Requirements (Gallons/Long Ton)	4,000
	Natural Gas Requirements (MCF/Long Ton)	10
	Water Flow (GPH)	12,500
	Production Rate (Long Tons/Hour)	~30
	Annual Production (Long Tons/Year)	250,000
B.	GEOTHERMAL WATER SUPPLY:	
	Supply Requirement (BBL/Yr; 335°F)	30,000,000
	Supply Requirement (BBL/Day; 335°F)	80,000
	Number of 40,000 BBL/Day Wells	2
	Production Well Cost ($)	4,000,000
	Gathering System	1,000,000
	Heat Exchangers	2,000,000
C.	YEARLY COSTS (Geothermal; 15 Year Life) [No Methane Production]	
	Capital Costs ($)	7,000,000
	Investment ($/Year)	900,000
	Maintenance ($/Year)	200,000
	Salaries & Wages ($/Year)	100,000
	Taxes, Insurance	140,000
	Total Operating Costs	1,340,000
	Profit (10%), Taxes (10%) [$/Year]	1,800,000
	Total Cash Flow ($/Year) [No Methane Credit]	3,140,000
D.	YEARLY COSTS (Geothermal; 15 Year Life) [Methane]	
	Capital Costs Added For Methane ($)	4,000,000
	Total Capital Costs ($)	11,000,000
	Investment ($/Year)	1,480,000
	Maintenance ($/Year)	400,000
	Salaries & Wages ($/Year)	300,000
	Taxes, Insurance	200,000
	Total Operating Costs	2,380,000
	Profit (10%), Taxes (10%) [$/Year]	2,200,000
	Total Cash Flow (Facility) [$/Year]	4,580,000
	Methane Flow (40 SCF/BBL) [MCF/Year]	2,200,000
	Methane Value ($2.00/MCF) [$/Year]	4,400,000
	Methane Severance Tax (7.5%) [$/Year]	-330,000
	Before Tax Methane Credit ($/Year)	4,070,000
	After Tax Methane Credit ($/Year)	2,120,000
	Annual Cost of Heat[1] ($/Year)	2,460,000
E.	YEARLY COST[2] (Methane For Boiler Heating)	
	Total Quantity Methane (MCF)[3]	2,500,000
	Methane Cost ($2.00/MCF) [$/Year]	5,000,000
F.	ESTIMATED ANNUAL SAVINGS ($/Year)	2,500,000

[1]Depletion allowance and intangibles are not considered.

[2]Note: No Boiler Capital, O & M, S & W, etc., costs included.

[3]Assume: 245 Btu/lb_m @ 80% efficiency.

E. BENEFICIATION OF GEOTHERMAL FLUIDS

Processing of natural geothermal fluids to increase their potential for industrial utilization--given the name "Beneficiation"--is presently only being accomplished by means of flashing steam from high-enthalpy geothermal liquids. Hornburg (1975) studied the pulp and paper and the sugar industries and found what appear to be economically feasible applications of geopressured geothermal fluids to U.S. Gulf Coast operations. For each industry, less than half of the total energy requirements were met by the geothermal resources, and each industrial plant required from 1 - 4 production wells capable of 40,000 BBLS/Day of geothermal fluids each.

A brief study of other Gulf Coast industry, as in Section C preceding, points out the inescapable fact that the vast majority of Gulf Coast industry requires heat of a higher quality than can be supplied from the presently expected geopressured geothermal resource. One then asks the question--what can be done to increase the enthalpy of the fluids in an economically and energetically feasible manner? The object is to broaden the spectrum of potential user industries using a beneficiation process.

Candidate beneficiation processes are:

(1) Natural gas, fuel oil, or coal topping by heating.

(2) Topping by heating followed by flashing.

(3) Steam flashing followed by externally-powered compression.

(4) Steam flashing followed by division of the steam flow--one part of the flow provides compression work for the remaining part of the flow.

(5) Gas turbine supplies compression work to flash steam; energy recovery from exhaust generates additional steam.

A multitude of other processes might be suggested; however, process (4) appears interesting for geopressured geothermal fluids in that both geohydraulic head and methane in solution are available. The following is a quick assessment of the technical, economic, and energetic considerations for a flash steam/compression beneficiation scheme.

TECHNICAL CONSIDERATIONS

Consider a fuel plant/process steam plant system. In order to limit the quantity of effort required, let us assume the 8.5 well fuel plant as proposed by Dow Chemical Company (see Appendix B, Figure 8). The process steam beneficiation plant is as shown in Figure VII-6. Approximate fluid states for the beneficiation plant are listed in Table VII-5, where the flow rates are based upon a single 40,000 BBL/Day well. It is clear that this beneficiation scheme will produce steam of reasonable superheat(277°F), temperature (585°F), pressure (78 psia), and flow rate (320,000 lb_m/hr for 10 wells) having a much wider industrial application. Further, the methane thought to be present in the geopressured geothermal fluids could be used either for a compressor/superheater powered by a gas turbine (obtain higher pressure and temperature) or a superheater (adding superheat). Used as a superheater, of the order of 100 - 140 Btu/lb_m can be added to the steam, resulting in a termperature of approximately 750 - 840°F.

Technically, this beneficiation process does not require any new technology except for the large steam compressors. Note that these compressors, unlike normal compressors, will not contain inter-coolers to remove heat generated in the gas by the inefficiency of the compression process. This is because the object is to increase the enthalpy of the steam as well as the pressure.

ENERGETIC CONSIDERATIONS

Table VII-6 presents the estimated capital costs and net energetics for the geopressured geothermal steam beneficiation plant of Figure VII-6. As can be seen from Table VII-6, the net energetics of the beneficiation plant are nearly as favorable as those for the electric generation plant. The energetics are not as favorable mainly because of the requirement to purchase electricity to run in-plant service equipment. Also, estimates for operations and maintenance costs for the well field are probably excessive by as much as 80%.

ECONOMIC CONSIDERATIONS

A preliminary economic analysis of the beneficiation plant is presented in Table VII-7 in the form of a levelized consolidated net income statement. The methane has been priced at $2.45 per thousand cubic feet and process heat at $2.00 per million Btu. The methane cash flow dominates the total cash flow (contributing 69% of the total) as in the electric power generation case. The delivered steam is priced at the price of natural gas (on a million Btu basis) without any conversion efficiency. Since the capital cost of boilers, gas turbines, water desalination units, auxiliaries,

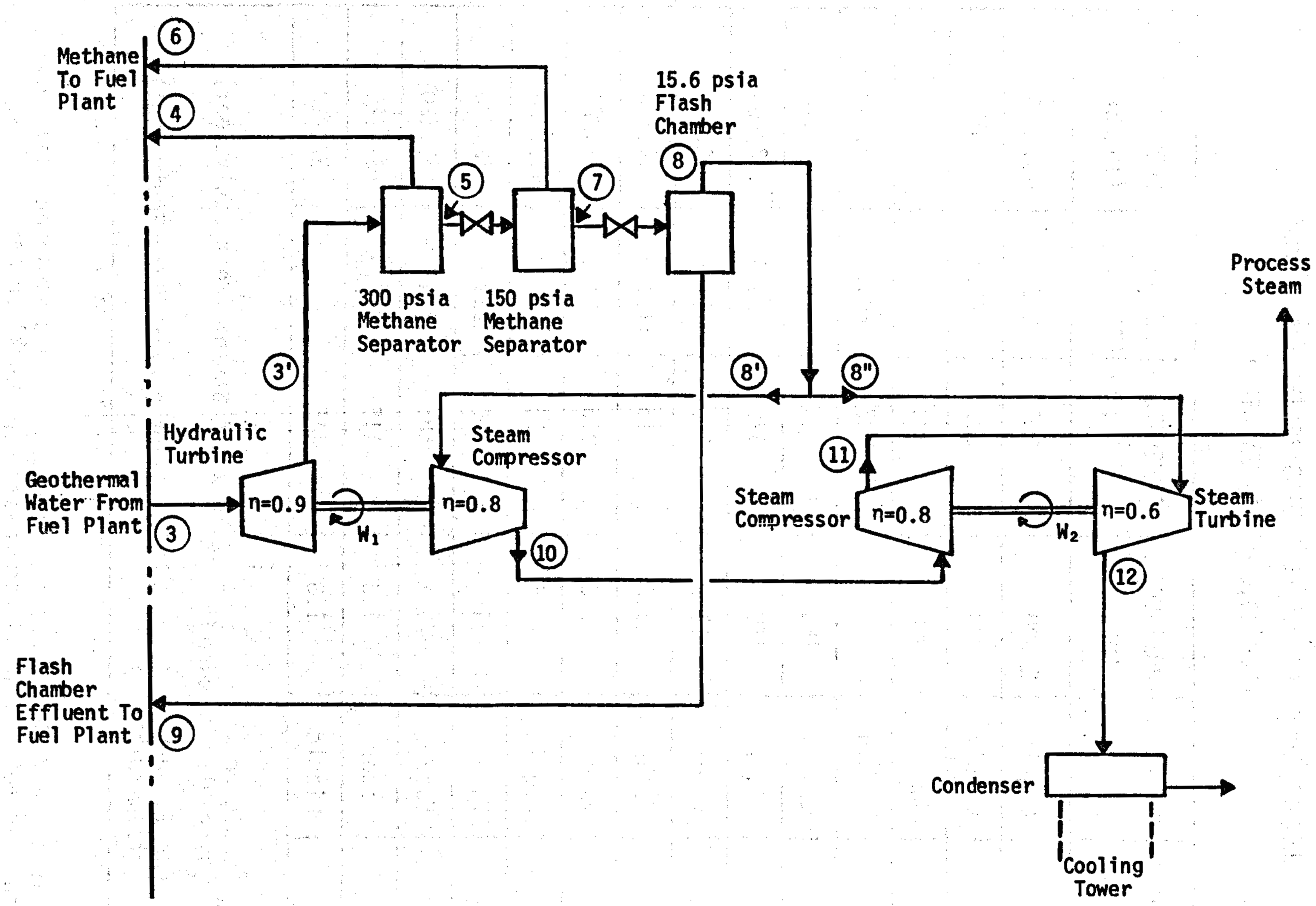


Figure VII-6: Process steam beneficiation plant using energy of fluids--self beneficiation.

TABLE VII-5

GEOPRESSURED GEOTHERMAL FLUIDS BENEFICIATION PLANT
(PER 40,000 BBL/DAY WELL)

STATE POINT	STATE	PRESSURE (psia)	TEMPERATURE (%F)	ENTHALPY (Btu/lb_m)	FLOW RATE (lb_m/hr)
3	Liquid	2,000	325	296.1	585,000
3'	Liquid	300	325	296.1	585,000
4	Gas	300	~323	---	1,542
5	Liquid	300	~323	294.1	583,500
6	Gas	150	320	---	276
7	Liquid	150	320	291.1	583,200
8	Vapor	15.6	215	1151.6	64,450
8'	Vapor	15.6	215	1151.6	32,220
8"	Vapor	15.6	215	1151.6	32,220
9	Liquid	15.6	215	183.2	518,700
10	Vapor	~35	380	1229 *	32,220
11	Vapor	~76	585	1324 *	32,220
12	Vapor	1.3	115	1057.0	32,220
13	Liquid	1.3	115		32,220

$$W_1 = \left\{\begin{matrix}\text{shaft work} \\ \text{hydraulic turbine}\end{matrix}\right\} = 2.50 \times 10^6 \text{ Btu/hr (Heat Equivalent)}$$

$$W_2 = \left\{\begin{matrix}\text{shaft work} \\ \text{steam turbine}\end{matrix}\right\} = 3.05 \times 10^6 \text{ Btu/hr (Heat Equivalent)}$$

*It is assumed that since intercoolers are not employed, the work which does not appear as compression (pv work) appears as heat transfer to the steam.

TABLE VII-6

NET ENERGETICS OF A 8.5 WELL STEAM BENEFICIATION PLANT

Architect/Engineer Item	SIC Category	Installed Cost (10^3\$)	Energy Factor (Btu/\$) [1963] ($x10^{-4}$)	Total Energy (Btu) ($x10^{-7}$)	Price Index Correction Factor (1963/1976)	Corrected Total Energy (Btu) ($x10^{-7}$)
I. Site Development						
A. Land, Lease, and Royalty Cost		Not Avail.				
B. Surveying	Miscellaneous Professional Services	9	2.6554	23	0.5291	13
C. Grading and Drainage	New Construction, Highways	14	9.8507	136	0.5291	72
D. Fencing	Miscellaneous Fabricator Wire Products	22	14.465	324	0.4883	160
E. Roads	New Construction, Highways	226	9.8507	2241	0.5291	1186
F. Water and Sanitary Services	Water and Sanitary Services	7	11.666	82	0.5291	42
G. Electric Power on Site	Electric Utilities	10	9.6952	97	0.3747	35
H. Lighting	Lighting Fixtures	5	7.6642	37	0.5291	20
I. Warehouse, Shop, Office	New Construction, Non-residential	75	6.6371	498	0.5291	262
J. Contingency 15%	Average of Site Development	55	9.3016	512	0.5216	267
II. Well Field						
A. Source Wells	Crude Petroleum and Natural Gas	40000	10.855	434000	0.4500	195400
B. Reinjection Wells	Crude Petroleum and Natural Gas	32800	10.855	356000	0.4500	160200
C. Collection and Disposal Piping	Pipe, Valves, and Pipe Fittings	1909	7.3742	14080	0.4883	6875
D. Reinjection Well Pumps and Drives	{a. 50% Pumps and Compressors; b. 50% Motors and Generators}	452	6.1816	2794	0.5577	1558
III. Methane Processing Plant						
A. Air Coolers	Refrigeration Machinery	40	6.4015	256	0.5577	143
B. Methane Compressors and Drives	{a. 50% Pumps and Compressors; b. 50% Motors and Generators}	990	6.1816	6120	0.5577	3413
C. Water Separators	Fabricated Plate Work	65	11.562	750	0.4883	367
D. Filter	General Industrial Machinery, n.e.c.	4	6.2497	25	0.5291	12
E. Glycol Dehydration System	Refrigeration Machinery	109	6.4015	698	0.5577	388
F. 2000# CH_4 Separator	Fabricated Plate Work	4708	11.562	54430	0.4883	26580
G. 300# CH_4 Separator	Fabricated Plate Work	360	11.562	4509	0.4883	2202
H. 150# CH_4 Separator	Fabricated Plate Work	270	11.562	3122	0.4883	1524
TOTAL SITE DEVELOPMENT		425	-----	3953	-----	2062
TOTAL FUEL PROCESSING PLANT		9362	-----	90738	-----	45125
TOTAL WELL FIELD		72800	-----	790200	-----	357000
IV. Beneficiation Plant						
A. Flash Chamber	Fabricated Plate Work	413	11.562	4775	0.4883	2332
B. Surface Condenser	Fabricated Plate Work	1418	11.562	16390	0.4883	8003
C. Vacuum Pump and Drive		300	6.1816	1854	0.5577	1034
D. Condensate Pump and Drive	{a. 50% Pumps and Compressors; b. 50% Motors and Generators}	24	6.1816	147	0.5577	83
E. C.T. Recirc. Pump and Drive		460	6.1816	2844	0.5577	1566
F. Motor Control	Industrial Controls	300	3.8656	1160	0.5291	614
G. Instruments	Electrical Measuring Equipment	200	3.8293	766	0.5291	404
H. Steam Turbine	Steam Engines and Turbines	1970	8.4232	16590	0.5577	9252
I. Hydraulic Turbine						
1. Turbine Hardware	Pumps and Compressors	440	5.8254	2563	0.5577	1429
2. Controls	Industrial Controls	180	3.8656	696	0.5291	368
3. Instruments	Electrical Measuring Equipment	105	3.8293	402	0.5291	213
4. Lube Oil System	General Industrial Machinery n.e.c.	90	6.2497	561	0.5577	314
J. Steam Compressors	Pumps and Compressors	1500	8.4232	12630	0.5577	7050
K. Foundations	New Construction, All Other	1680	7.1266	11970	0.5464	6540
L. Site Development	(See Table VII-6, TOTAL SITE DEVELOPMENT)	425		3953		2062
M. Cooling Tower						
1. Tower	Wood Products n.e.c.	850	5.2875	4494	0.5291	2378
2. Piping and Valves	Pipe, Valves, and Pipe Fitting	490	7.3742	3613	0.4883	1764
3. Blowdown	[See note to Table IV-3 for	20	6.5164	130	0.5291	69
4. Make Up	Apportioning Costs for Blowdown]	80	6.5164	520	0.5291	276
TOTAL BENEFICIATION PLANT EQUIPMENT		10945	-----	86062	-----	45452
V. Operations and Maintenance						
A. Conversion Equipment						
1. Insurance	Insurance Carriers	992	2.5	2479	0.5500	1364
2. Property Taxes	Government Industries	2834	3.0	8502	0.5000	4251
3. Salaries (Operations)	Miscellaneous Professional Services	5100	2.6554	13540	0.5291	7166
4. Administration	Miscellaneous Professional Services	425	2.6554	1129	0.5291	597
5. Maintenance	Maintenance and Repair Construction	10200	7.5	76500	0.5291	40480
B. Fuel Processing						
1. Insurance	Insurance Carriers	983	2.5	2458	0.5500	1352
2. Property Taxes	Government Industries	2809	3.0	8426	0.5000	4213
3. Salaries (Operations)	Miscellaneous Professional Services	4213	2.6554	11190	0.5291	5919
4. Administration	Miscellaneous Professional Services	420	2.6554	1119	0.5291	592
5. Maintenance	Maintenance and Repair Construction	8426	7.5	63190	0.5291	33440
C. Well Field						
1. Insurance	Insurance Carriers	7644	2.5	19110	0.5500	10510
2. Property Taxes	Government Industries	21800	3.0	65520	0.5000	32760
3. Salaries (Operations)	Miscellaneous Professional Services	2180	2.6554	5800	0.5291	3068
4. Administration	Miscellaneous Professional Services	1090	2.6554	2900	0.5291	1534
5. Maintenance	Maintenance and Repair Construction	16140	7.5	130500	0.5291	69040
VI. Operating Electricity (1.6 MWe)		-----	-----	133500	-----	133500
TOTAL OF OPERATIONS AND MAINTENANCE		83563	-----	411360	-----	216300
TOTAL ESTIMATED CONSTRUCTION ENERGY		83745	-----	876260	-----	402450
TOTAL OF OPERATING ELECTRICITY		-----	-----	133500	-----	133500
TOTAL ENERGY REQUIRED		-----	-----	1421100	-----	752200
TOTAL ENERGY PRODUCED (30 YRS)	METHANE = {12.9×10^{13}(th); 4.60×10^{13}(e)}	PROCESS HEAT = {8.09×10^{13}(th); 3.02×10^{13}(e)}		TOTAL = 7.98×10^{13}		R = 0.094
RECOVERY YEARS				YEARS = 2.8		

*n.e.c. is defined as "not elsewhere classified."

TABLE VII-7

PRELIMINARY ECONOMIC ANALYSIS
OF BENEFICIATION PLANT

CONSOLIDATED NET INCOME STATEMENT
(LEVELIZED YEAR)
[$$10^6$]

1.	REVENUES		18.40
	(a) Methane	12.69	
	(b) Process Steam @ $2.00/$10^6$ Btu	5.71	
2.	EXPENSES		-3.65
	(a) Electricity	0.65	
	(b) Operations, Maintenance	2.05	
	(c) Methane Severence Tax	0.95	
3.	DEPRECIATION		-3.31
	(a) Well Field (15 yrs)	2.42	
	(b) Fuel Process Plant (30 yrs)	0.53	
	(c) Beneficiation Plant (30 yrs)	0.36	
4.	NET INCOME		11.44
5.	INTEREST		-3.30
	(a) Well Field	1.83	
	(b) Remainder	1.47	
6.	TAXABLE INCOME		8.14
7.	FEDERAL TAX (48%)		-3.91
8.	NET PROFIT		4.23
9.	AVAILABLE DISTRIBUTION		7.54
10.	AMORTIZATION		-3.31
11.	AFTER TAX EARNINGS		4.23
12.	PERCENT RETURN ON INVESTMENT ($63.30 x 10^6)		~6.7%

and operations and maintenance need not be added to the process steam price, it appears that the beneficiation process is economically justified providing methane and well field production rates are as hypothesized. One should note that the economic analysis included the installation of two complete well fields during the fuel processing and beneficiation plant life.

The capital charges for various items total 29.1% of total investment. These breakdown as follows:

Operating Expenses	5.76%
Depreciation	5.23%
Interest	5.21%
Federal Taxes	6.19%
Profits	6.68%
TOTAL	29.07%

The capital charges are similar to those used for the generating plant.

SUMMARY OF BENEFICIATION

The beneficiation plant considered in this section represents only one of a number of possible variations. The plant produces 30,200 x 10^9 Btu per year of 584°F, 76 psia, 1,324 Btu/lb_m steam. Of the ten chemical and petrochemical industries in the Corpus Christi area, only one consumes more process heat per year. Thus, the scale is of the proper order even though considerable process heat will be of a higher quality.

No technical, economic, or energetics problems of major proportion have been identified on this first, brief study of beneficiation. It appears that further study is fully justified and is recommended.

F. OTHER UTILIZATION

A number of specific industrial applications, in addition to the pulp, paper, and sugar cane industries studied by Hornburg (1975), deserve to be mentioned. Among these are: petroleum and natural gas pipelining, process heat for coal desulfurization and preparation as a boiler fuel, uranium leaching, large scale crushing and conveying, lumber and concrete block kilning, secondary recovery of petroleum, makeup for coal slurry pipeline, agricultural operations, and makeup for power plant cooling lakes. A brief discussion of each potential use follows.

1. PETROLEUM AND NATURAL GAS PIPELINING

Petroleum pipelining companies operate throughout the geopressured geothermal area from the Rio Grande Valley of Texas to Southwestern Mississippi. In areas of South Louisiana, Upper Texas (Freeport to Beaumont), and Middle Texas (Freeport to Corpus Christi), maps of pipelines appear similar to a heap of spaghetti. Gulf Coastal Plain pumping stations consume large quantities of energy. Technology development could lead to flash steam-driven, to secondary working fluid-driven, or to total flow-driven compressors and pumps. The quantity of energy required near to a geothermal resource will dictate possible future utilization.

2. COAL DESULFURIZATION AND PREPARATION

There are a number of processes the purpose of which is to prepare either processed solid fuel or liquid fuel from high-sulfur, high-ash coal. Much of the lignite found along the Texas Gulf Coast region is either high sulfur or high ash or both. Currently, stack-gas particulate separators and scrubbers are being proposed by regulatory authorities as environmental protection measures. However, solvent refining of 3% sulfur, high-ash Kentucky and Illinois coals will produce solvent-refined coal of 0.8% sulfur and 0.1% ash content. This product can be fired directly in boilers as both ash and sulfur content are within the EPA solid-fuel standards. No work has yet proceeded on lower-grade fuels such as lignite.

The H-coal liquifaction process uses a catalytic hydrogenation method for coal liquifaction. The objective is to produce liquid products containing less than 0.5% sulfur and having very low ash contents. Whether similar methods are applicable to lignite and might later be required for Northern Great Plains coal is not now known.

These types of coal processing will require large quantities of process heat, pumping, and conveying. Geothermal energy may well be applicable to all or part of these requirements. A relevant factor is that large-scale coal preparation plants could be located wherever the geothermal resource was located as long as coal (or converted natural gas) generation of power was relatively nearby.

3. URANIUM LEACHING

Uranium deposits too deep and to thin for conventional mining techniques have been found and developed in Live Oak County. Other similar ore bodies are being prospected and/or developed along the same mineralization trend. Unless new trends to the south and east are discovered, however, the use of geothermal fluids for uranium leaching is doubtful. In addition to resource location, there is an important question of whether the total dissolved solids and saline fractions could be tolerated in the mining operations.

4. CRUSHING AND CONVEYING

Steam, hydrocarbon vapor, or total flow expansion processes could provide significant quantities of energy for large-scale crushing, conveying, and sizing operations. It does not appear, however, that many such operations will ever exist within the geopressured geothermal zone. Rail transport of uncrushed or unprocessed materials to a suitable, lower-cost energy site might be a viable operation.

5. LUMBER AND CONCRETE PRODUCTS KILNING

Typical kilns for lumber drying and concrete products curing require low-quality steam or heated air. These facilities could easily be operated from geothermal fluids of 275 - 300°F or higher. Part of the problem is that the energy requirements are usually too small compared to production from more than one well, so that the drilling success rate must be very high in order to keep heat costs low.

6. SECONDARY RECOVERY OF PETROLEUM

Considerable quantities of saline fluids are injected into petroleum reservoirs each year in order to enhance product recovery. Two particular points are important, however: (a) rates of injection in a given field generally are not of the order of single geothermal well production or the even larger utilization facility effluent flow rates, (b) reinjected fluids are generally the same fluids produced concurrently with oil and/or gas from the same or nearby fields. Many, perhaps most, oil and gas production fields have a surplus of saline fluids, the disposal of which is usually by reinjection into reservoirs not containing hydrocarbons.

The thermal content of either the production or the conversion system effluent brines could be both a positive factor and/or a negative factor. Should an oil reservoir contain oil of API gravity 20 or slightly less, the temperature of the injected brine may enhance recovery by heating the oil, reducing its viscosity, and increasing production for a given pressure distribution in the reservoir. Generally, oil reservoirs of appropriate API gravity are not found on the Texas and Louisiana Gulf Coast Plain. A temperature increase in the reservoir may be detrimental to ultimate recovery even though some increased secondary recovery resulted. This is because the higher reservoir temperature could cause surfactants to have a much shorter effective lifetime than at the lower original temperature. The shortened surfactant lifetime results in more rapid decline of secondary recovery and less economic secondary recovery.

7. MAKEUP FOR COAL SLURRY PIPELINES

Slurry pipelines for coal have been proposed for transport of coal from the Northern Great Plains to Texas. An important environmental problem is the water required to create the slurry and the disposal and/or cleanup of the slurry water if the coal is dewatered prior to boiler combustion. Transport of brine makeup water from the Gulf Coast Plain to Colorado, Montana, or Wyoming will be expensive as there is an elevation difference of 5,000 to 7,500 feet. Friction pressure losses, over the very great distances involved, overwhelm the potential head recovery from the slurry except at points where reasonably rapid elevation changes occur. Where head recovery from the slurry is possible, the recovered energy could be used to pump makeup water towards the coal fields. A good economics and energetics study will be necessary to assess the viability of the proposition.

An important issue arising from the coal slurry use is the effect of dissolved solids in the brine. To what extent would the solids be adsorbed or absorbed in the coal and how would brine solids absorbed into the coal appear as pollutants? Could the absorbed solids foul particulate precipitators and overload stack gas scrubbers? Finally it is important to know if the use of the brine would cause corrosion, scaling, and reduced service life for pipeline components (pumps, valves, pipe, etc.).

8. MAKEUP FOR POWER PLANT COOLING LAKES

Each year potable water becomes more scarce everywhere on the Gulf Coast Plain. Yet, the requirement for cooling water for industry and for electric generation increases. The large coal-fired and nuclear generation units currently being constructed on the Gulf Coast will increase generation capacity and cooling water consumption considerably. Consequently, alternative cooling water sources will need to be developed--both to cool new and existing generation plants. Geothermal brines may be useful for this purpose. The key issues are: protection of ground water from saline water intrusion, protection of surface water during high rainfall, and protection of power plant once-through condensers to prevent corrosion and scaling.

9. AGRICULTURAL OPERATIONS

In general, for agricultural operations to be an attractive geothermal utilization market, the fuel supply system must be inexpensive, the agricultural operation must be very intensive, or the agricultural utilization must be a utilization secondary to the principal utilization. Further, unless agrucultural use is a secondary use, the problem of appropriate load factor is always a problem except, perhaps, in intensive integrated operations as hot houses, hydroponics, etc. Climate will usually be an important factor.

Climate along the United States Gulf Coast is generally mild except during summer, when temperatures and humidities rise above optimum for many crops. Some freezing temperatures occur during winter, but not for extended periods of time. Frost days may number from zero to a maximum of 20 or 30 per winter. As a rule, freezes are very light with more than five degrees of freeze being infrequent. Hence, freeze prevention (frost protection) has a reasonably low priority. The only major citrus area in Texas and Louisiana, the Rio Grande Valley, has no more than five light freeze days per year. Frost protection by itself will be highly uneconomical.

In some regions of the coast, winter and summer greenhousing to maintain optimum growing conditions is feasible as average winter temperatures are too low and average summer temperatures are too high. An especially attractive operation is the hydroponics operation, which is very much more non-solar energy intensive. Even for these operations, spring and fall represent very low load conditions. Fall low-load conditions could be overcome with grain drying, a reasonably large volume operation for large areas of the Texas Gulf Plain.

The conclusions for potential agricultural use are: unless the agricultural operations are very intense and very coordinated, agricultural utilization of geopressured geothermal fluids independent of a major base-load utilization will be uneconomic because of the very large fuel plant capital costs.

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